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The International Satellite Cloud Climatology Project (ISCCP): The First Project of the World Climate Research Programme

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"Who is wise enough to number all the clouds?" *Job 38:37*

Abstract

The International Satellite Cloud Climatology Project (ISCCP) has been approved as the first project of the World Climate Research Programme (WCRP) and will begin its operational phase in July 1983. Its basic objective is to collect and analyze satellite radiance data to infer the global distribution of cloud radiative properties in order to improve the modeling of cloud effects on climate. ISCCP has two components, operational and research. The operational component takes advantage of the global coverage provided by the current and planned international array of geostationary and polar-orbiting meteorological satellites during the 1980s to produce a five-year global satellite radiance and cloud data set. The main and most important characteristic of these data will be their globally uniform coverage of various indices of cloud cover. The research component of ISCCP will coordinate studies to validate the climatology, to improve cloud analysis algorithms, to improve modeling of cloud effects in climate models, and to investigate the role of clouds in the atmosphere's radiation budget and hydrologic cycle. Validation will involve comparative measurements at a number of test areas selected as representative of major (or difficult) cloud types and meteorological conditions. Complimentary efforts within the framework of WCRP will promote the use of the resulting ISCCP data sets in climate research.

1. Introduction

The Preliminary Plan for the World Climate Research Programme (WCRP), published in January 1981, stresses the importance of cloudiness in controlling the radiation budget of the earth's climate system. Clouds, which display great variability in space and time, as well as in type, can influence climate through many complex interactions involving the hydrological cycle; however, their dominant role is in controlling the 3-dimensional field of radiative fluxes in the atmosphere. In turn, these radiative fluxes drive the thermally forced general circulations of the earth's atmosphere and oceans. These circulations then form clouds and a major climate feedback loop is joined. The WCRP plan thus recognizes the need to develop a uniform global cloud climatology as part of a broad research program on climate processes.

Cloud climatologies are derivable from two basic sources: data acquired by satellites and data acquired from ground-based and aircraft observations. The representativeness of cloud statistics derived solely from conventional ground-based

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TABLE 1. Data Specifications for the International Satellite Cloud Climatology Project.

Parameters−Spatial and temporal averages and variances (or another statistical measure of the shape of the temporal distribution) are required for each of the following parameters.

Amounts	Precision (*30-day averages*)
Total cloud amount (fraction)*	±0.03
Cirrus cloud amount (fraction)*	±0.05
Middle cloud amount (fraction)	±0.05
Low cloud amount (fraction)*	±0.05
Deep convective cloud amount (fraction)	±0.05
Heights	
Cirrus cloud-top height (km)*	±1.00
Middle-level cloud-top height (km)	±1.00
Low-level cloud-top height (km)	±0.50
Deep convective cloud-top height (km)	±1.00
Cloud-top temperature (*K*) for each cloud category*	±1.00
Cloud optical depth	
Cloud size distribution	
Average narrow-band radiances (VIS and IR)*	

Spatial averaging−The information is to be averaged over approximately 250 km by 250 km boxes.

Time sampling−Every three hours, i.e., eight times a day, centered around the synoptic observation times.

Time averaging−The global cloud climatology should consists of 30-day averages for each of the eight observing times per day.

Length of time series−Five years.

*Highest priority.

observations is limited in the amount of spatial and temporal coverage that is provided. The network of operational satellites available during the 1980s not only provides global observations, but also provides higher spatial and temporal resolution. Both conventional and satellite data suffer from a problem of obscuration of one cloud layer by another; however, the cloud cover seen from space governs the more important radiative effects of clouds; namely, their effects on solar radiation and on the thermal emission of the earth-atmosphere system as a whole. In any event, the two kinds of data are complementary, each to some extent offsetting the limitations of the other, and therefore both data sets should be collected and merged to create a more complete cloud climatology.

Prior to 1960, several global cloud climatologies based on surface observations were constructed (especially London, 1957; Telegadas and London, 1954). Although many years of data were included in the averages, sampling was so sparse, especially over the oceans, that only monthly mean values of sky cover, cloud base altitude, and cloud type were reported. The advent of routine satellite observations made global coverage, as well as direct observation of those cloud properties most relevant to the earth's radiation budget, possible. The two most extensive satellite-based cloud climatologies compiled to date are by Sadler (Sadler, 1969; Sadler *et al*., 1976) and by Miller and Feddes (1971), but both of these data sets report on cloud amount only, without any correction for variations in the background and in the viewing geometry.

These cloud climatologies do not contain sufficient information on cloud-top temperature (or altitude) or on the optical properties of clouds required by climate modelers to calculate the first-order effects of clouds on the earth's radiation budget or the climate feedbacks produced by cloud variations (Stockholm, 1975). Improved knowledge of the global cloud distribution and its variation on diurnal, seasonal, and interannual time scales is critical to further progress in understanding our climate (Oxford, 1978; New York, 1981). Recent improvements in both the quality of satellite observations and the techniques for deducing cloud properties from satellite data suggest that obtaining a global climatology to meet the needs of climate research is now possible.

2. Scientific objectives

The investigation of the role of clouds in climate involves the study of many complex dynamic and thermodynamic processes. The International Satellite Cloud Climatology Project (ISCCP) will not explicitly investigate all scientific questions, but will focus on the creation of a climatology of cloud radiative properties and promote relevant research using these data. The radiance and cloud data sets produced by ISCCP will then be a key element in ongoing research on cloud effects on the earth's radiation budget, particularly cloud radiative feedbacks, and on cloud-radiation parameterization in climate models. These climatologies also will contribute to research on many other cloud-related problems, such as site selection for solar energy power plants. The basic ISCCP scientific objectives given in the Preliminary Implementation Plan (World Climate Program, 1982) are:

1) To produce a global, reduced-resolution, calibrated and normalized, infrared and visible radiance data set, along with basic information on the radiative properties of the

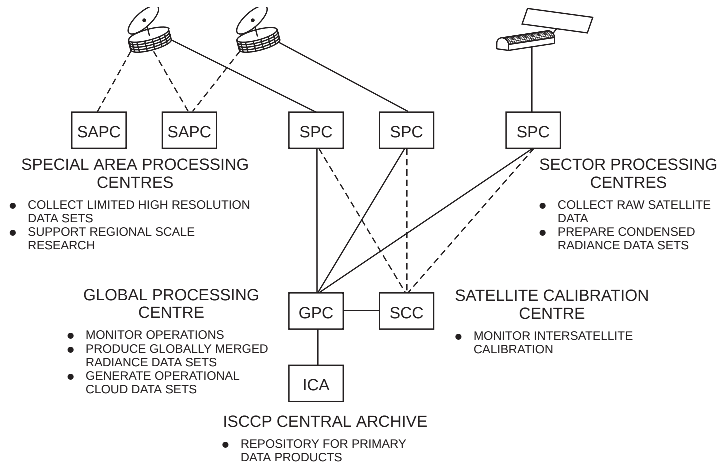

FIG. 1. ISCCP data management concept.

atmosphere, from which cloud parameters can bederived.

2) To coordinate basic research on techniques for inferring the physical properties of cloud from satellite radiance data, and to derive and validate a global cloud climatology.
3) To promote research using ISCCP data to improve parameterizations of clouds in climate models, and to improve understanding of the earth's radiation budget and the hydrological cycle.

Specifications for the ISCCP cloud climatology are summarized in Table 1.

3. ISCCP observing system

The operational five-year data collection period will begin in mid-1983. Data will be sought from five geostationary meteorological satellites (GOES-E, GOES-W, GMS, INSAT, and METEOSAT, as well as from at least one NOAA/TIROS-N-type polar orbiter, and possibly from a METEOR-class polar orbiter. The primary data will be the two standard visible (0.6 μm) and IR (11 μm) channels common (roughly) to all of the satellites. Measurements from any other spectral channels, when available, also will be collected to aid in distinguishing cloud types. The polar-orbiting satellites are essential to the project for providing the following:

1) coverage of the polar regions not viewed by the geostationary satellites;
2) a basis for normalization of the radiances observed by the different geostationary satellites;
3) global coverage (although at the expense of diurnal sampling) that may help mitigate the possible loss of one or more geostationary satellites;
4) multispectral observations for discriminating cloud properties not derivable from the primary two-channel geostationary data.

Because the conversion of satellite-measured upwelling radiances to cloud properties still requires research, the project will archive the radiance data set so that the conversion to cloud properties can be repeated with improved cloud algorithms. The basic data flow is dictated by three factors:

1) The archive of radiance and cloud data must be a usable archive, in that its volume must be constrained for practical applications.
2) The raw radiance data direct from the satellite must be reduced to a usable archive in real time, since it is not practical to reprocess the vast quantities of raw data in a delayed mode.
3) In view of the foregoing, the gathering and initial reduction of satellite data must be shared among various facilities around the world.

4. Data management

The overall ISCCP data management concept is illustrated in Fig. 1. The major centers responsible for acquisition, processing, and archiving the large quantities of satellite data are: the Sector Processing Centres (SPC); the Special Area Processing Centres (SAPC); the Satellite Calibration Centre (SCC); the Global Processing Centre (GPC); and the ISCCP Central Archive (ICA).

At the original full resolution, a complete global data set from six satellites would occupy over 60,000 high density (6250 bpi) tapes per year. Using the data-processing strategy adopted, the satellite radiances and the derived cloud properties will be stored on fewer than 150 tapes per year.

Each SPC (satellite operator or other facility with direct readout capability) will produce radiance data sets that have been reduced in volume by reducing the visible channel resolution to match the IR channel (10 km) and by further sampling to a spacing of about 30 km. Also, SAPCs will produce limited quantities of high-resolution data for selected regions and times. These data will be used in cloud-radiation research, algorithm improvement studies, and validation of the operational climatology. The SCC, using high-resolution data sets from SPCs, will normalize all satellite radiometers to the NOAA polar orbiter radiometer, which will be calibrated operationally. The GPC will produce a reduced volume, normalized, and calibrated global radiance data set collected from SPCs and produce an experimental cloud climatology data set using the project-approved algorithm. The ICA will archive and catalog all of the radiance and cloud data sets produced by ISCCP centers, including the basic meteorological data sets used to derive cloud properties from satellite radiances. Additional data for validating the climatology or for defining thermodynamic processes that affect cloudiness are expected to be available through existing sources of conventional data. The WCDP will assist in coordinating all of these data sources.

5. Data Management System Test (DMST)

An end-to-end systems test is planned for March−April 1983 to provide a broad test of many of the proposed concepts, system elements, and interfaces involved in the observational and data management systems. Such a test, with a data collection period of seven days, provides an early opportunity to verify procedures and uncover difficulties in executing all of the steps outlined previously. Principal groups participating in the test are:

European Space Agency	−SPC for METEOSAT
Atmospheric Environment Service, Canada	−SPC for GOES-E
Colorado State University, USA	−SPC for GOES-W
NOAA/NESDIS, USA	−SPC for NOAA-7, ICA
University of Cologne, FRG	−SCC
Weather Bureau, RSA	−SAPC for METEOSAT
University of Wisconsin, USA	−SAPC for GOES-E and GOES-W
National Center for Atmospheric Research, USA	−Test user of SAPC data
NASA Goddard Institute for Space Studies, USA	−GPC.

6. Cloud analysis algorithm

In order to evaluate currently available cloud analysis schemes and define the ISCCP operational algorithm, a pilot study was initiated in late 1981 (World Climate Program, 1982) with the objective of comparing the results produced by each method when applied to the same satellite radiance data. In addition, the study was to evaluate the variation of the algorithms' sensitivity to clouds when satellite data volume is compressed in different ways. The radiance data selected to accomplish these objectives were full-resolution GOES-E visible (1 km resolution) and infrared (8 km resolution) radiances, taken every three hours from 5 to 19 February 1979. Corresponding TIROS-N data were included (4 km resolution). These data cover three geographic regions (eastern U.S. and Canada, northeastern Brazil, and northern Chile) that include ocean and land, subtropical stratocumulus, tropical convection, strong midlatitude winter storms, snow-covered land, and lake ice cover. This data set covers a long enough time period to evaluate the statistical properties of the analyses, includes data

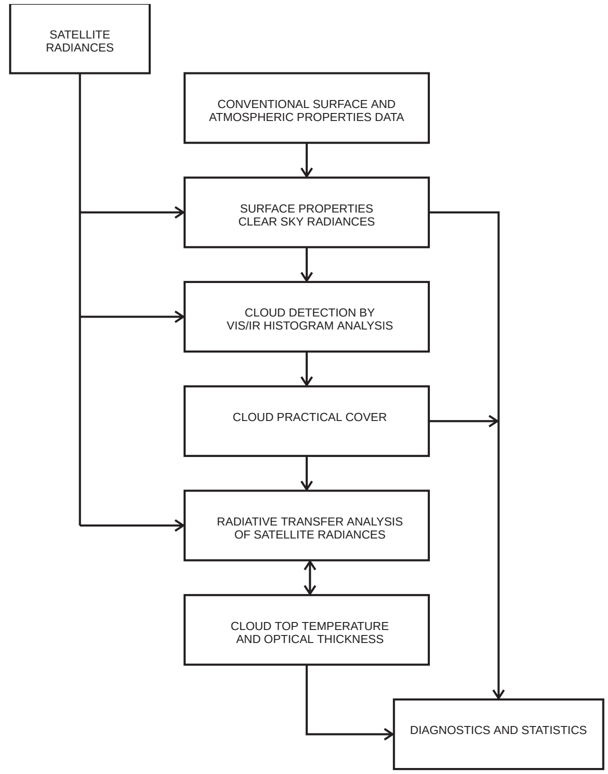

FIG. 2. Schematic of ISCCP cloud analysis algorithm.

over the whole diurnal cycle, and presents many different situations to challenge the analysis methods. Each analysis algorithm was applied to these radiance data at full, 8 km, and 32 km resolutions, with the 8 km results sampled to 32 km spacing. Two workshops have been held to consider the results of applying about seven different analysis schemes to the pilot data, one in Ottawa from 31 May to 1 June 1982 and one in New York from 9 to 11 December 1982.

In a general sense, cloud analysis algorithms perform two functions: to decide which radiance values correspond to cloudy scenes and to infer cloud properties from the radiance values. The first function is equivalent to a comparison of two radiance values, one representing a cloud-free scene, to decide if the observation indicates the presence of clouds. The second function is equivalent to comparing the magnitude of the observed differences in radiance caused by cloud to a model of cloud effects on the radiances. The seven algorithms tested differed in the method of specifying or identifying the cloud-free radiance values, relied on different combinations of the visible and infrared radiances to detect clouds, employed different cloud models with a range of complexity, and used differing amounts of additional information to specify atmospheric and surface properties.

Figure 2 shows a schematic of the ISCCP operational cloud analysis algorithm that has been defined based on the pilot study. The first step in the analysis combines a statistical analysis of the time variation of satellite radiance data for each location with conventional atmospheric and surface properties data to obtain a specification of cloud-free radiances. The statistical radiance analysis obtains a time average cloud-free radiance that bypasses all of the complications of relating the physical properties of the surface and atmosphere to satellite radiometer measurements. The actual time variation is accounted for by varying the average values according to the variation of conventional surface data about their own time average. One of the disadvantages of conventional data, their poor coverage of ocean areas, is not a problem in this case, since ocean areas are much less time-variable than land areas; i.e., conventional data density is highest where the variability is largest – on land.

The cloud detection component of the algorithm employs a second statistical analysis of the radiances, in this case an analysis of the distribution of radiances over a mesoscale area at each particular time. The largest disagreement between different analysis algorithms occurs with moderate cloud cover; but in these cases, enough cloud-free area is present at mesoscale to produce a distinct peak in a radiance frequency-of-occurrence histogram. If this peak is "close" to the cloud-free radiances determined in step one, then cloud-free scenes will be detected reliably. In summary, the first two analysis steps analyze the complete time and space distribution of the observed radiances, together with auxiliary information about the surface, to infer the presence of clouds.

Given a specification of cloud-free radiances and cloud cover amount, the satellite radiance measurements associated with cloudy scenes can be compared to radiative transfer calculations to derive the cloud-top temperature and visible optical thickness of the clouds. These three quantities (or their equivalent) describe the principal radiative effects of clouds. The radiative transfer model can include non-isotropic surface reflectivity, variable surface emissivity, variable scattering and absorption by the atmosphere (ozone absorption of visible and water vapor absorption of infrared radiances), and variable atmospheric temperature, as well as variations in the cloud properties. The cloud model that will be employed is a single-layer, plane-parallel cloud with a specified particle-size distribution (which may be a function of cloud temperature). Figure 2 indicates a double-headed arrow at this point in the analysis because the derivation of physical cloud properties allows diagnostic analysis to adjust for known effects. For example, low optical thickness clouds have infrared emissivities less than unity, making brightness temperatures greater than their physical temperatures; this effect can be accounted for at this point in the analysis.

The final step of the analysis includes the calculation of the statistics (e.g., monthly mean) that compose the cloud climatology, but also will incorporate all of the information specifying the radiative properties of each location at each time. This climatology of the variables that influence the radiation budget of earth's atmosphere also will allow diagnosis of cloud types and provide valuable information on the interaction of clouds with other components of the climate.

The pilot study continues to test and develop the detailed characteristics of this algorithm. In particular, the use of radiance statistics and auxiliary data in the first part of the analysis needs to be tested in the polar regions, where clear and cloudy sky radiances are not related as simply and surface-atmospheric conditions are extremely variable. Further testing of methods to correct for overestimates of cloud cover fraction using low-resolution data also will be carried out.

While continuing cloud analysis research is expected to produce improved analysis algorithms, the ISCCP objective is to produce a uniform five-year climatology. Thus, adoption of improved algorithms will be considered only on evidence developed as part of the validation program.

7. Research strategy

The operational component of ISCCP will produce global radiance and cloud climatology data sets that can be used in many aspects of cloud-climate research. In addition, special regional and local data sets can be produced to study specific cloud-radiation problems. The IAMAP Radiation Commission, through its ad hoc Working Group on Clouds and Radiation, will assist in the development of an ISCCP research strategy and coordination plan that will contribute to the following:

1) improved scientific algorithms for retrieving physical cloud properties from satellite-observed radiances;
2) improved descriptions of cloud development and estimates of radiative fluxes for comparison with climate model results to improve their cloud parameterizations;
3) improved interpretation of radiative fluxes as observed by NASA's Earth Radiation Budget Experiment (ERBE) and other satellites, leading to improved understanding of cloud-radiative feedbacks on climate.

The major project contribution to these research problems will come through a program to validate the operational cloud climatology through comparison of ISCCP-derived quantities with those observed during the field phases of other atmospheric research programs and those obtained using other satellites (such as LANDSAT, SPOT,[3] and VISSR Atmospheric Sounder (VAS)) with higher resolution or more spectral channels. These data sets, though more restricted in time and space coverage, can be employed to develop improved cloud retrieval algorithms and to provide more complete physical descriptions of different cloud types than can be obtained from the operational satellites directly.

In addition to special, higher-resolution data sets to support the validation and algorithm development program, ISCCP SAPCs may produce a number of regional data sets to support investigations of cloudiness development on meso- and synoptic scales and comparisons with radiance fields generated by climate models. These data sets will vary in their properties according to purpose, but two types of areas are envisioned to support research efforts: small (~250 km square) areas for coordination with field studies, for validation efforts, and for provision of local climatologies; and large (~2000 km square) areas for special synoptic studies. Such large areas might include the Indian monsoon area (in connection with the Monsoon Climate Programme), north-west Europe, and the eastern North Atlantic (North Atlantic storms), as well as a tropical region of the Mid-Pacific (ITCZ, El Niño).

Planning is already under way in the United States for defining such a broad research program in relation to ISCCP (Vonder Haar *et al*., 1983). The two emerging foci for this research are: 1) global and regional intercomparisons between climatologies of cloud parameters derived from satellites and

[3]French Earth Resources Satellite.

from atmospheric general circulation models; and 2) a regional experiment (FIRE (First ISCCP Regional Experiment)) to develop and test new cloud and radiation parameterization methods.

Both foci aim ultimately at the improvement of climate models. Satellite-observed upwelling radiances and derived cloud data are useful to climate modelers for developing and improving cloud-radiation parameterization schemes for GCMS and for validating overall model performance. FIRE will involve intensive case studies of several high-resolution regions, including the continental United States and tropical Pacific, and may involve the establishment of one or more SAPCs. Furthermore, FIRE will compliment the ERBE satellite mission by determining the radiative budget at the earth's surface and within the atmosphere.

8. Milestones

Major milestones for ISCCP are:

23-29 March 1983	ISCCP DMST
7-8 April	Third Cloud Algorithm Intercomparison Workshop, New York
25-27 May	Second session of the ISCCP Working Group on Data Management (WG/DM) to review and finalize the Data Management Plan, New York
1 July	Begin ISCCP operational data processing
22-25 August	ISCCP Research Workshop, Hamburg (in conjunction with the International Union of Geodesy and Geophysics (IUGG) meeting)
February 1984	Third session of WG/DM to assess ISCCP first results.

9. Summary

The ISCCP global and special-area radiances and cloud data sets, when analyzed in conjunction with other field studies and conventional data describing the physical state of the atmosphere and surface and with earth radiation budget and other satellite observations, will provide new knowledge of the components of the 3-dimensional radiation balance and its variation, particularly the role played by clouds. This information will support basic research on techniques for cloud-radiation parameterizations in climate models and also will help in understanding key processes in the atmosphere (e.g., the hydrologic cycle) as part of WCRP.

The project will coordinate research on validating the cloud climatology and seek to promote wide use of the data sets produced. There will be ample opportunity for interested scientists or research institutions to participate in ISCCP by coordinating field experiments or other satellite observations, testing experimental cloud retrieval algorithms, or comparing cloud climatology results with climate models. As the U.S. plan for FIRE evolves, the scientific community will be advised regarding opportunities for submitting unsolicited proposals for support to the appropriate funding agencies. Similar activities in other countries are encouraged strongly.

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